pMSSM scan for future colliders (& more)

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Link to twiki

Intro to pMSSM

- Most SUSY searches are optimized in terms of simplified models (2-3 free parameters)
- However, the full MSSM contains 120 free parameters
- The pMSSM goes **beyond simplified models**, but uses motivated assumptions to reduce the total number of parameters to a more tenable **19 parameters**:

$\tan\beta$: the ratio of the vev of the two–Higgs doublet fields.
M_A: the mass of the pseudoscalar Higgs boson
μ: the Higgs–higgsino mass parameter
M_1, M_2, M_3: the bino, wino and gluino mass parameters.
$m_{\tilde{q}}, m_{\tilde{u}_R}, m_{\tilde{d}_R}, m_{\tilde{l}}, m_{\tilde{e}_R}$: first/second generation sfermion masses
$m_{\tilde{Q}}, m_{\tilde{t}_R}, m_{\tilde{b}_R}, m_{\tilde{L}}, m_{\tilde{\tau}_R}$: third generation sfermion masses
A_t, A_b, A_τ: third generation trilinear couplings.

arXiv 9901246

Goal of Snowmass pMSSM scan

- Explore future sensitivity in a framework that goes **beyond simplified SUSY models**
- Understand the physics potential of different future experiments in the context of the pMSSM
  - How will SUSY sensitivity from various collider scenarios overlap/complement each other?
  - What interesting pMSSM models have limited coverage, and how can we expand this coverage?
- **Complementarity** across Snowmass Frontiers: input from dark matter, rare frontier, etc.
  - What does the recent muon g-2 measurement tell us about viable pMSSM models and their accessibility at future colliders?

Overview of pMSSM scan strategy

- **1. Sample points** in the 19D pMSSM space
  - Most progress so far has been on this step
- **2. Focus in** on interesting regions of phase space
- **3. Generate** signal events
- **4. Perform analyses** for each collider scenario
- **5. Compare performance** of different future experiments

1. **Sample points** in the 19D pMSSM space

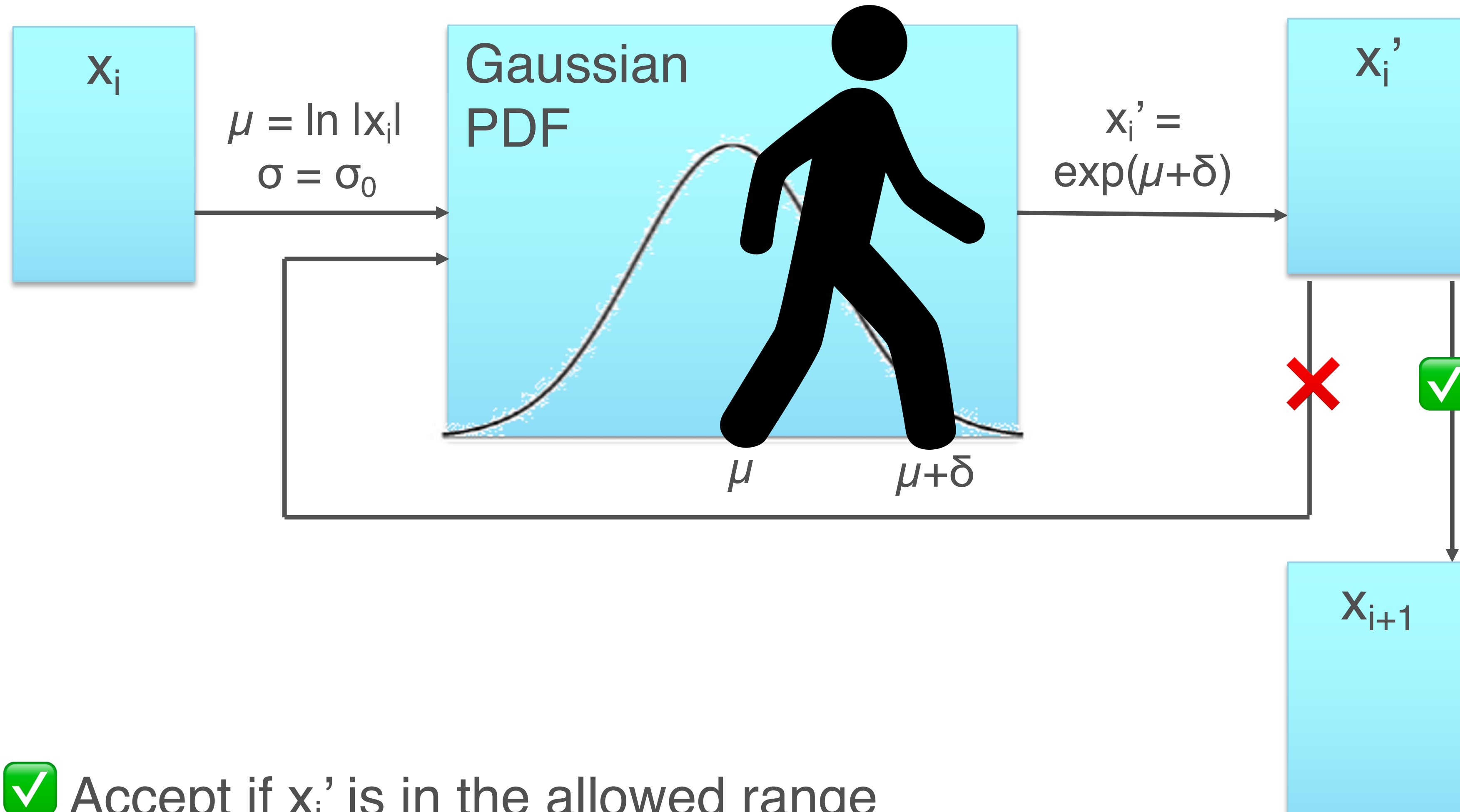
- We will perform a **grand scan** that aims to cover the OR of accessible ranges of many collider scenarios, up to 100 TeV pp collider
- This is a HUGE parameter space. Use a **Markov chain Monte Carlo** to step through the space in a smart way
  - Use **logarithmic stepping** to populate low values of mass parameters more densely than high values
  - **Likelihood** for accepting/rejecting a point is based on existing experimental results

pMSSM parameter ranges

Parameter	Minimum	Maximum	Stepping
tan β	1	60	Log
M_A	100 GeV	25 TeV	Log
$\|\mu\|$	80 GeV	25 TeV	Log
$\|M_1\|$	1 GeV	25 TeV	Log
$\|M_2\|$	70 GeV	25 TeV	Log
M_3	200 GeV	50 TeV	Log
$m_L 123\sim$, $m_e 123\sim$	90 GeV	25 TeV	Log
$m_Q 12\sim$, $m_u 12\sim$, $m_d 12\sim$	200 GeV	50 TeV	Log
$m_Q 3\sim$, $m_u 3\sim$, $m_d 3\sim$	100 GeV	50 TeV	Log
$\|A_b\|$, $\|A_\tau\|$	1 GeV	7 TeV	Log
$\|A_t\|$	1 GeV	$3\sqrt{(m_Q 3\sim m_u 3\sim)}$	Log

Maxima chosen to cover points accessible at a 100 TeV collider

Logarithmic stepping in the McMC



✅ Accept if x_i' is in the allowed range and $L(x_i')$ satisfies criteria

Logarithmic stepping in the McMC

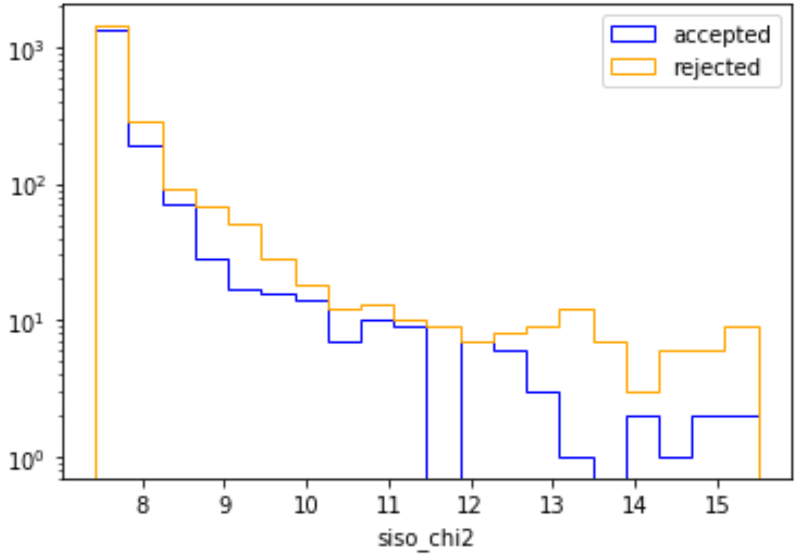
- Log stepping ensures that **lower masses are explored with finer granularity** than higher masses
  - Low masses: ~degeneracy between SUSY and SM particles gives more **diverse signatures**
  - Width σ_0 determines the fraction of high mass points
- Using log stepping, the McMC **cannot cross zero**, but some parameters can have ± values
  - **Initial conditions** for each scan will be chosen at random, including signs. Keep the initial parameter signs
  - **Many threads** with different initial signs will be launched in parallel and combined

McMC likelihood

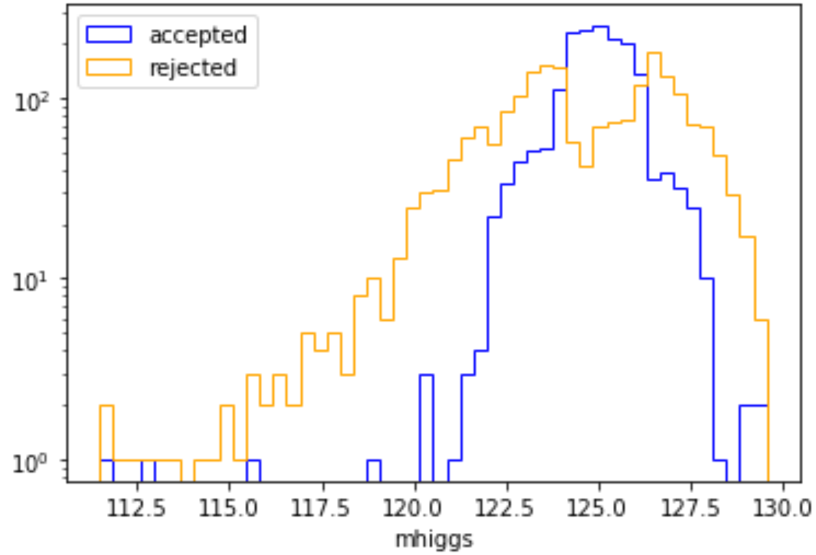
- Calculate the **likelihood** of each pMSSM point based on its agreement with existing measurements
  - The McMC prefers to take steps to new points with higher likelihood (better agreement with measurements)

Example 4000 point scan:

B-physics observables χ^2



Higgs boson mass



McMC likelihood

- Contributions from **SPheno** and **FeynHiggs**: Gaussian with mean/width = experimental value/uncertainty
- Contributions from **Superiso**, **HiggsSignals**, and **HiggsBounds**: χ^2 is calculated directly by the program

Superiso 4.0	**SPheno 4.0.4**	**FeynHiggs 2.18.0**	**Higgs Signals 2.6.0**	**Higgs Bounds 5.9.1**
$\Delta_0(B \rightarrow K\gamma)$	$BR(B^+ \rightarrow \tau\nu)$	m_W	LHC Higgs meas.	LHC Heavy $H(\tau\tau)$
$BR(b \rightarrow s\gamma)$	$BR(D_s \rightarrow \tau\nu)$	$\Delta(\rho)$		
$BR(B_s \rightarrow \mu\mu)$	$BR(D_s \rightarrow \mu\nu)$	m_H, H properties		
$BR(B_d \rightarrow \mu\mu)$	α_S			
$BR(b \rightarrow s\mu\mu)$	m_{top}			
$BR(b \rightarrow see)$	m_{bottom}			
$BR(B0 \rightarrow K^{*0}\gamma)$				

Fermilab

2. **Focus in** on interesting regions of phase space

- We can’t simulate events for every pMSSM point!
- Could decide to **not simulate inaccessible points**
  - With small cross sections / low yield, or based on truth-based likelihood (as ATLAS does)
- Could **focus the scan by over-sampling**, i.e. simulating a high density of points in interesting regions:
  - Near the measured muon g-2
  - With DM relic density consistent with observations
  - Satisfying naturalness criteria
  - With particular signatures, e.g. disappearing tracks or long-lived particles

3. **Generate** signal events

- Signal events can be generated by feeding SLHA files into Pythia, then Pythia events through Delphes
  - Workflow is being developed
- For some studies, signal cross section is enough
- SM backgrounds to be provided by EF MC production group for many collider setups
  - Details in John's slides

4. Perform analyses

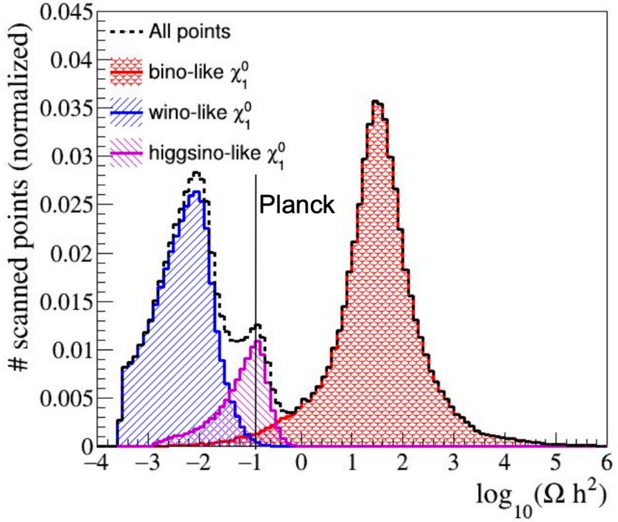
- Once we have pMSSM signal points, need to perform analysis to determine sensitivity
- Largely through **crowdsourcing**
  – pMSSM points and generated signal events will be made available to everyone
  – Interested groups are encouraged to include the pMSSM points as signal in their analyses
- More groups using the scan points for studies = more complete comparison as the final product
  – Let us know if you want a particular collider setup for generated signal events, etc.
  – Want to extend beyond just EF (dark matter, rare, etc.)

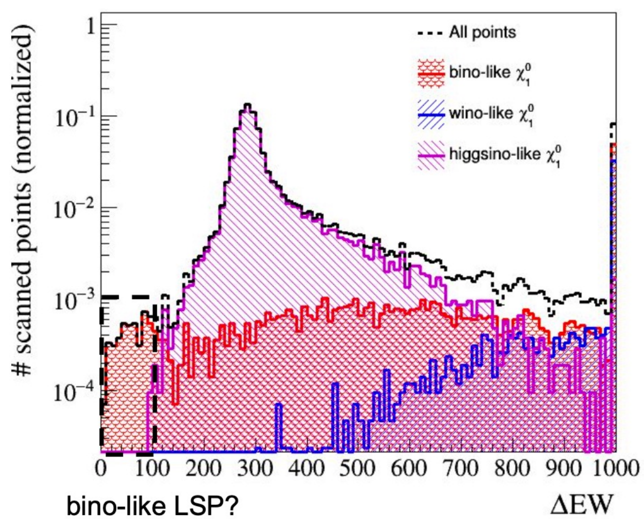
5. Compare performance

- **How do interesting observables depend on pMSSM parameter values?**
  - Especially interesting for this scan, which extends ranges far beyond those performed for LHC studies
- **Compare the sensitivity of different colliders**
  - Assuming SM observation, pMSSM points are excluded at some threshold (e.g. 95% CL)
  - How do the different scenarios **complement each other**? Are there **uncovered regions**?
  - What is coverage like in experimentally interesting regions, e.g. near the measured muon g-2?

5. Compare performance

- **How do interesting observables depend on pMSSM parameter values?**
- Inspiration plots from M. Mroweitz, CMS pMSSM team:
  - Observables broken down by composition of χ^0_1



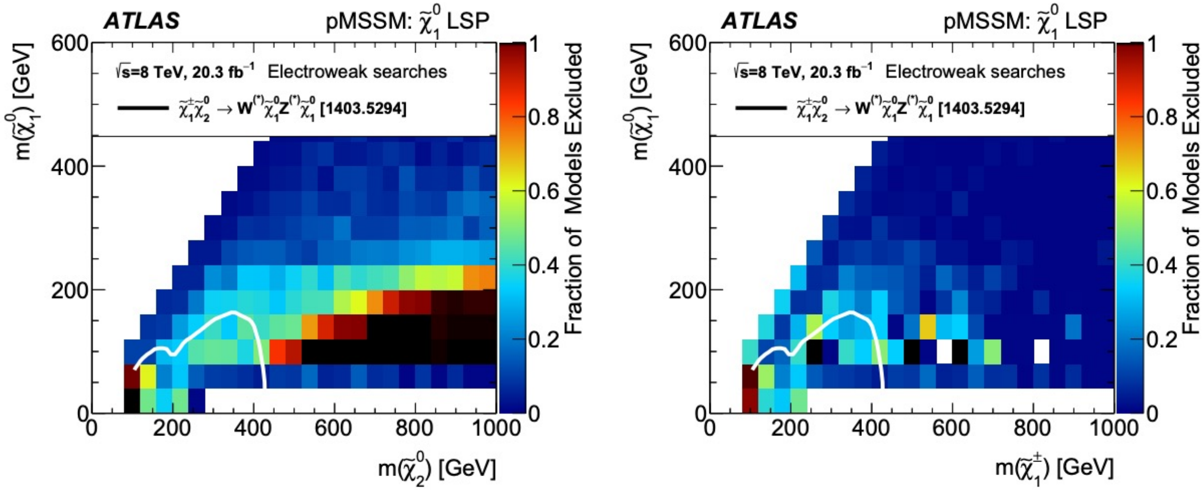


EW fine-tuning parameter

- Can look at many observables (e.g. muon g-2) for different ranges of pMSSM parameters

5. Compare performance

- **Compare the sensitivity of different colliders**
- Inspiration plots from ATLAS Run 1 pMSSM scan:



(a) Neutralinos (b) Chargino–neutralino

Excluded region is actually not well covered in terms of pMSSM

- Can calculate e.g. contours of constant fraction of models excluded and overlay collider scenarios
- Can look at scanned points excluded by > 1, =1, or no future collider scenarios

Conclusions

- The technical implementation is in place for a **pMSSM grand scan** using Markov chain Monte Carlo
  - **Likelihood** based on existing measurements steers the scan away from excluded regions
  - **Logarithmic stepping** ensures the whole phase space is explored, while populating low parameter values with high density
- Brainstorming what signal points to focus on/generate
  - Feedback is welcome
- Workflow for signal MC generation is under development
- Have some preliminary ideas for summary plots
  - Feel free to share yours as well